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**(54) A shaped charge liner including bismuth**

Wismut enthaltende Einlage für Hohlladung

Revêtement contenant du bismuth pour charge creuse

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**Description****BACKGROUND OF THE INVENTION**

5 The subject matter of the present invention relates to a liner for shaped charges as well as a method for making such a liner. More particularly, the invention provides a liner of a shaped charge which is comprised of Bismuth and Copper powders instead of Lead and Copper powders.

10 Shaped charges, which may, for example, be used in a perforating gun for perforating a wellbore, include a case, an explosive material packed against the inner wall of the case, and a liner for lining the explosive material. Upon detonation, the explosive material expands thereby collapsing the liner and forming a jet. When used in a perforating gun, the jet from the shaped charge perforates a formation traversed by the wellbore. The liner of the shaped charge is normally made of Lead and Copper; such a liner, made from powdered Copper and Lead, is disclosed in US-A-4 794 990. When the liner collapses and forms the jet, the Lead and Copper elements in the liner are deposited in the formation. From an environmental point of view, it is not desirable to deposit Lead in the formation. Therefore, a new 15 shaped charge is needed, one which includes a liner that does not incorporate Lead as one of its constituent elements.

15 It is already known, from DE-A-27 24 036 and US-A-4 557 771, that the liner of a shaped charge can include Bismuth; however, DE-A-2 724 036 discloses shaped charges with solid metal liners made from an alloy having a Bismuth content, rather than liners made from metal powders; whereas US-A-4 557 771 discloses a liner made of Cu powder mixed with bismuth.

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**SUMMARY OF THE INVENTION**

Accordingly, it is a primary object of the invention to provide a shaped charge, which may be adapted for use in a 25 perforating gun, that produces a jet which, from an environmental point of view, is clearly superior to the known lead based shaped charged of the prior art, but does not include lead.

According to one aspect of the present invention, there is provided a liner which does not include lead as a constituent element, for use in a shaped charge, said liner being made of copper powder and bismuth, characterised in that said bismuth is a bismuth powder, the percent by weight of bismuth powder being greater than or equal to 10% and less than or equal to 20% and the percent by weight of copper powder being greater than or equal to 80% and 30 less than or equal to 90%, and further characterised in that said copper powder is of three different kinds, respectively having roughly spherical, irregular and dendritic particle shapes.

According to another aspect of the present invention, there is provided a method of making the liner of the preceding paragraph, the method comprising blending copper powder with bismuth powder, and further including blending graphite and a lubricant with said copper and bismuth powders.

35 Further scope of applicability of the present invention will become apparent from the detailed description presented hereinafter. It should be understood, however, that the detailed description and the specific examples, while representing a preferred embodiment of the present invention, are given by way of illustration only, since various changes and modifications within the spirit and scope of the invention will become obvious to one skilled in the art from a reading of the following detailed description.

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**BRIEF DESCRIPTION OF THE DRAWINGS**

A full understanding of the present invention will be obtained from the detailed description of the preferred embodiment presented hereinbelow, and the accompanying drawings, which are given by way of illustration only and are not 45 intended to be limitative of the present invention, and wherein:

figure 1 illustrates a typical shaped charge having a case, an explosive material, and a liner, where the liner is comprised of Bismuth and Copper, and not Lead and Copper.

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**DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT**

Referring to figure 1, a typical shaped charge adapted for use in a perforating gun is illustrated. This particular shaped charge is discussed in U.S. Patent 4,724,767 to Asetline, issued February 16, 1988, the disclosure of which is incorporated by reference into this specification.

55 In figure 1, the shaped charge includes a case 10, an explosive material 12, such as RDX, packed against the inner wall of case 10, and a liner 14 lining the explosive material 12. When a detonating cord ignites the explosive material 12, the liner 14 collapses thereby forming a jet. The jet propagates outwardly along a longitudinal axis of the shaped charge. When the shaped charge is disposed in a perforating gun which is situated in a wellbore, the jet from the shaped charge perforates a formation traversed by the wellbore.

Normally, the liner of a prior art shaped charge is comprised of Lead and Copper powders. When the liner collapses thereby forming a jet, the Lead and Copper elements are deposited into the formation. From an environmental point of view, it is not desirable to deposit Lead in the formation. Therefore, a new shaped charge liner is needed which does not include Lead as a constituent element.

5 In accordance with the present invention, the Lead element, present as a constituent element within the liner of the prior art shaped charge, is being replaced by the element Bismuth. Accordingly, in figure 1, the shaped charge liner 14, in accordance with the present invention, is comprised of Bismuth and Copper, and not Lead and Copper. Shooting tests indicate that a shaped charge having a liner 14 comprised of ten percent (10%) by weight of Bismuth, as a binder, and ninety percent (90%) by weight of a three-Copper blend can shoot as well as the standard shaped charge having a liner which is normally comprised of twenty percent (20%) Lead and eighty percent (80%) Copper. Alternatively, shooting tests also indicate that a shaped charge having a liner 14 comprised of twenty percent (20%) by weight of Bismuth, as a binder, and eighty percent (80%) by weight of a three-Copper blend can shoot as well as the standard shaped charge having a liner which is comprised of the standard Lead and Copper. Less than ten percent (10%) Bismuth does not yield the required performance; and greater than twenty percent (20%) Bismuth is too costly. Therefore, any shaped charge including a liner 14 having a composition in the range from 10% Bismuth/90% Copper to 20% Bismuth/80% Copper will perform well.

10 Bismuth was chosen for a number of reasons. Bismuth is non-toxic, melts at 271°C (519.8 degrees F), and boils at 1560°C (2840 degrees F). Its specific gravity is 9.75 (Lead is 11.34), and Bismuth is one of the least expensive of the "heavy" metals. In addition, it is believed that the presence of an easily vaporized component (such as Lead or 15 Bismuth) in a liner 14 of a shaped charge is important because the radially dispersed metallic vapor, produced from the Lead or Bismuth element, tends to impart inward momentum to the balance of the jet being produced from the collapsed liner 14, keeping it focused and aligned. Therefore, since Bismuth has a low boiling point and a low heat of vaporization, similar to Lead, Bismuth was chosen as an adequate substitute for the Lead element in the liner 14 of the shaped charge of figure 1. In addition, Bismuth, like Lead, has virtually no solid solubility in Copper. Like lead, 20 Bismuth is easily deformed at low stresses and therefore can mechanically bind the copper particles to one another without interdiffusion or alloying, yielding good green strength and ensuring a jet of particulate particles rather than a solid jet.

25 In figure 1, the liner 14 of the shaped charge is comprised of:

(1) Bismuth powder, as a binder; the percent by weight of the Bismuth powder in liner 14 lies in a range from greater 30 than or equal to ten percent (10%) to less than or equal to twenty percent (20%); and (2) a blend of three Copper powders, each including particles having a different particle shape, that is, a three-Copper, three particle morphology blend. The exact amounts and percentages of each constituent element of Bismuth and Copper, incorporated in the liner 14 of the shaped charge of figure 1, are disclosed below in the following working examples.

35 Example 1

To make an improved liner 14 for a shaped charge, in accordance with the present invention, which would normally include Lead and Copper, replace the Lead element with Bismuth. Start by making 0.4536 kg (1 pound) blend of the Bismuth and Copper, which 0.4536 kg (1 pound) blend is comprised of:

40 (1) 20% by weight, or 90.80 gms, of Bismuth powder; the Bismuth powder must include particles which have an irregular particle shape produced by grinding;

45 (2) 80% by weight, or 363.20 gms total, of a blend which consists of three Copper powders, each Copper powder including particles having a different particle shape. The blend of three Copper powders is comprised of the following:

50 (a) 64% by weight, or 290.56 gms, Copper powder including gas or water atomized particles having roughly spherical shape; this powder may be obtainable from the Canadian Metal Powders Corporation;

(b) 12% by weight, or 54.48 gms, Copper powder including electrochemically reduced copper having irregular particle shape; this powder is obtainable from the U.S. Bronze Corporation, Flemington, New Jersey; ask for grade R278; and

55 (c) 4% by weight, or 18.16 gms, Copper powder including electrolytically deposited copper having dendritic particle shape; this powder is obtainable from U.S. Bronze Corporation, Flemington, New Jersey; ask for grade D101;

(3) the normal amount of graphite and lubricant, which consists of 30.83 ml alcohol, 0.05 gms stearic acid, and 1.362 gms graphite.

This blend, when tested according to ASTM B331-85 and ASTM B312-82 will have a Green density of at least 8.0 g/cc and a Green strength of at least 12411.10<sup>3</sup> Pa (1800 psi).

In figure 1, the liner 14 includes a skirt 16 and an apex 18. A taper exists in the thickness of the liner 14, starting with the apex 18 and ending with the skirt 16. Imagine a circle 20 which traverses the circumference of the liner 14; the thickness variation of the liner 14 around the circle 20 is identified as "delta T". Therefore, the objective is to make a shaped charge liner, similar to liner 14 of figure 1, having the following specifications:

weight: 32 to 36 grams  
 delta T: plus or minus 0.0177 mm (0.0007 inches)  
 thickness of the skirt 16: 1.52 mm (.060) to 1.75 mm (.069) inches  
 taper: 0.294 mm (0.0116 inches) at apex to 0.314 mm (0.0124) inches at skirt

Given the above referenced composition of the liner 14 and the above specifications, a liner 14 was made, a shaped charge was made using the liner 14, and the following results were obtained when a perforating gun was made which included the new shaped charge having the new liner 14 and the perforating gun perforated a formation traversed by a cased wellbore:

Using a concrete target which hardened 3 days after being initially poured, the following test results were obtained, where "penetration" describes the radial depth of penetration of the target, in inches, produced by the jet of the new shaped charge liner 14 of the present invention, and "casing hole dimensions" describes the shape of the hole produced by the jet in a steel casing. The shape of the hole in the casing is further described by the following legend: A X B, where A is the length of the major axis of an ellipse or circle in mm (inches), and B is the length of the minor axis of the ellipse or circle in mm (inches).

	penetration of formation	casing hole dimensions indicative of circular shape
a.	564.1 mm (21.50 inches)	0.48 X 0.48 (a perfect circle)
b.	590.55 mm (23.25 inches)	0.49 X 0.47 (imperfect circle)
c.	517.65 mm (20.38 inches)	0.50 X 0.49 (imperfect circle)
d.	571.50 mm (22.50 inches)	0.47 X 0.45 (imperfect circle)

The above test results indicate that the liner 14 of a shaped charge, in accordance with the present invention, made with Bismuth and Copper, performs just as well, if not better, than a prior art liner made with Lead and Copper; that is, the depth of penetration of the target by the liner 14 of the present invention is just as good, if not better, than the depth of penetration of the formation normally produced by the prior art shaped charge liner, and the entrance hole size and eccentricity are at least as good.

#### Example 2

Start by making a 0.4536 kg (1 pound) blend of the Bismuth and Copper, which 1 pound blend is comprised of:

(1) 10% by weight, or 45.40 gms, of Bismuth powder; the Bismuth powder must include particles which have an irregular particle shape produced by grinding;

(2) 90% by weight, or 408.60 gms total, of a blend which consists of three Copper powders, each Copper powder including particles having a different particle shape. The blend of three Copper powders is comprised of the following:

(a) 72% by weight, or 326.88 gms, Copper powder including gas or water atomized particles having roughly spherical shape; this powder may be obtainable from the Alcan Metal Powders Division of the Alcan Aluminum Corporation, Elizabeth, New Jersey

(b) 13.5% by weight, or 61.29 gms, Copper powder including electrochemically reduced copper having irregular particle shape; this powder is obtainable from the U.S. Bronze Corporation, Flemington, New Jersey; ask for grade R278; and

(c) 4.5% by weight, or 20.43 gms, Copper powder including electrolytically deposited copper having dendritic particle shape; this powder is obtainable from U.S. Bronze Corporation, Flemington, New Jersey; ask for grade D101;

- 5 (3) the normal amount of graphite and lubricant, which consists of 30.83 ml alcohol, 0.45 gms stearic acid, and 1.362 gms graphite.

10 Using a concrete target which hardened 3 days after being initially poured, the following test results were obtained, where "penetration" describes the radial depth of penetration of the target, in inches, produced by the jet of the new shaped charge liner 14 of the present invention, and "casing hole dimensions" describes the shape of the hole produced by the jet in a steel casing. The shape of the hole in the casing is further described by the following legend: A X B, where A is the length of the major axis of an ellipse or circle in inches, and B is the length of the minor axis of the ellipse or circle in inches.

	penetration of formation	casing hole dimensions indicative of circular shape
a.	441,45 mm (17.38 inches)	0.46 X 0.44 (imperfect circle)
b.	450,85 mm (17.75 inches)	0.43 X 0.41 (imperfect circle)
c.	520,7 mm (20.50 inches)	0.47 X 0.47 (a perfect circle)

20 The above test results again indicate that the liner 14 of a shaped charge, in accordance with the present invention, made with Bismuth and Copper, performs just as well, if not better, than a prior art liner made with Lead and Copper; that is, the depth of penetration of the formation by the liner 14 of the present invention is just as good, if not better, than the depth of penetration of the formation normally produced by the prior art shaped charge liner.

25 In summary, the liner 14 of the shaped charge in accordance with the present invention comprises Bismuth powder (which replaces the lead powder) and Copper powder. The percent by weight of the Bismuth powder in liner 14 lies in a range from greater than or equal to 10% to less than or equal to 20%. The remaining ingredients are primarily Copper powders; however, the normal amounts of graphite and lubricant is also included.

30 **Claims**

1. A liner for use in a shaped charge, said liner being made of a blend of copper powder and bismuth, characterised in that said bismuth is a bismuth powder, the percent by weight of bismuth powder being greater than or equal to 10% and less than or equal to 20% and the percent by weight of copper powder being greater than or equal to 80% ad less than or equal to 90%, and further characterised in that said liner does not include lead as a constituent element and said copper powder is of three different kinds, respectively having roughly spherical, irregular and dendritic particle shapes.
2. The liner of claim 1, wherein said copper powder comprises a first copper powder including gas or water atomized particles having said roughly spherical shape, a second copper powder including electrochemically reduced copper having said irregular particle shape, and a third copper powder including electrolytically deposited copper having said dendritic particle shape.
3. The liner of claim 1 or claim 2, further comprising graphite and a lubricant within said blend of metal powders.
4. The liner of claim 3, wherein said lubricant comprises alcohol and stearic acid.
5. A shaped charge including a liner in accordance with any one of the preceding claims.
6. A method of making the liner according to claim 3, the method comprising blending copper powder with bismuth powder, and further including blending graphite and a lubricant with said copper and bismuth powders.

55 **Patentansprüche**

1. Eine Auskleidung zur Verwendung in einer Hohlladung, welche Auskleidung aus einem Gemisch von Kupferpulver und Wismut hergestellt ist, dadurch gekennzeichnet, daß das Wismut ein Wismutpulver ist, der prozentuale Ge-

FIG.1

